AD-A134 093 COLLISIONAL EXCITATION AND RADIATION OF ATOMS AND MOLECULES(U) WISCONSIN UNIV-MADISON DEPT OF PHYSICS C C LIN 19 AUG 83 AFOSR-TR-83-0802 AFOSR-78-3649 1/1

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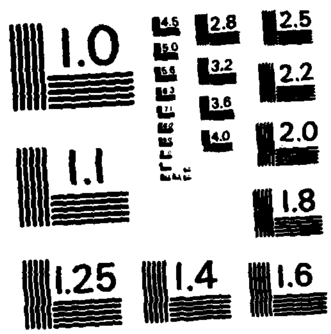
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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFOSR-TR- 83-0802	2. GOVT ACCESSION NO. AD-A120513	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Collisional Excitation and Radiation of Atoms and Molecules		5. TYPE OF REPORT & PERIOD COVERED Final Technical Report 1 July 1978 - 30 June 1983
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Chun C. Lin		8. CONTRACT OR GRANT NUMBER(s) AFOSR-78-3649
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Physics, University of Wisconsin-Madison, 1150 University Ave., Madison, WI 53706		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 61102F 2301/A4
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Office of Scientific Research, NP Bolling Air Force Base, D. C. 20332		12. REPORT DATE August 19, 1983
		13. NUMBER OF PAGES 4
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

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18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

electron-impact excitation, dissociative excitation, excitation cross sections, metastable levels, radiation, atoms, molecules

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The general objectives of this research project are to study collisional excitation of atoms and molecules and the radiation emitted by these excited atoms and molecules. Our major efforts include (a) electron excitation of the sodium and xenon atoms, (b) excitation of electronic states of nitrogen molecules, (c) formation of excited nitrogen atoms by electron-impact dissociation of nitrogen molecules, (d) Measurement of electron excitation cross sections of metastable levels of neon atoms, (e) excitation of atoms by H^+, H^o, H^- impact.

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Final Scientific Report

Grant AFOSR-78-3649, 1 July 1978 - 30 June 1983

The general objectives of this research project are to study excitation of atoms and molecules by collisions and the subsequent radiation produced by the excited atoms and molecules. Our major efforts were in the following areas.

1. Electron Excitation of Atoms. Absolute electron-impact optical excitation functions of 26 transitions of the sharp, principal, diffuse, fundamental, and nP-4S series of sodium have been measured in the impact-energy range 0-150 eV. The determination of the target-atom number density was made by measuring the attenuation of sodium resonance radiation from a fluorescence cell upon passage through the collision chamber. Direct excitation cross sections of fourteen states (4S, 5S, 6S, 7S, 3P, 4P, 5P, 6P, 3D, 4D, 5D, 6D, 6F, and 7F) have been determined and the results are compared with theoretical calculations based on the Born approximation and the method of multi-state close coupling.

Optical cross sections have been measured for some 100 emission lines of the xenon atom produced by electron-impact excitation for incident electron energies from threshold to 100 eV. From these optical data we determine the direct excitation cross sections for all ten 2p levels (the $5p^5 6p$ configuration) as well as the apparent excitation cross sections of a number of levels from the $5p^5 ns$ and $5p^5 nd$ configurations.

2. Excitation of Electronic States of Molecules by Electron Impact. Electron-impact excitation of the $D^3\Sigma_u^+$ and $c_4'^1\Sigma_u^+$ electronic states of the N_2 molecule has been studied by measuring optical excitation cross sections of the $D^3\Sigma_u^+(v'=o) \rightarrow B^3\Pi_g(v'')$ and $c_4'\,^1\Sigma_u^+(v'=o) \rightarrow a^1\Pi_g(v'')$ emission. Both $D^3\Sigma_u^+$ and $c_4'\,^1\Sigma_u^+$ are Rydberg molecular states, hence their excitation cross sections are of special interest. The excitation function of the $D^3\Sigma_u^+$ state differs from those of many triplet states in that it exhibits a double-peak structure. We attribute this feature to inherent properties of direct excitation of $D^3\Sigma_u^+$ rather than secondary processes such as cascade. We have also studied electron-impact excitation of the $b^3\Sigma^+$, $d^3\Delta_i$, and $a'^3\Sigma^+$ electronic states of the CO molecule. Optical cross sections for emission of the Third Positive System ($b^3\Sigma^+ \rightarrow a^3\Pi$), the Triplet System ($d^3\Sigma_i \rightarrow a^3\Pi$), and the Asundi System ($a'^3\Sigma^+ \rightarrow a^3\Pi$) of the CO molecule produced by electron excitation have been measured.

3. Formation of Excited Nitrogen Atoms by Electron-Impact Dissociation of Nitrogen Molecules. A systematic study of the production of excited nitrogen atoms in the ^4S, ^4P, ^4D, ^4F, ^2P, ^2D terms of the $2p^23p$, $2p^23d$, $2p^24d$, and $2p^23p'$ configurations by electron-impact dissociation of N_2 has been made by measuring the intensity of the radiation emitted by these species. We have measured the optical excitation cross sections for a series of emission lines of the type $2p^23p \rightarrow 2p^23s$, $2p^23d \rightarrow 2p^23p$, $2p^24d \rightarrow 2p^23p$, $2p^23p' \rightarrow 2p^23s'$ for incident electron energy from threshold to 200 eV. From the near-threshold behaviors of the measured excitation functions, we are able to characterize the nature of the excited electronic states of N_2 that are mainly responsible for the dissociation process.

4. A New Method for Measuring Electron Excitation Cross Sections of Metastable Levels of Atoms and Molecules. In the usual optical method for studying electron excitation, one determines the electron excitation cross section by measuring the radiation emitted by the atoms that are lifted to the excited state of interest by electron impact. This procedure fails if the excited state is metastable since there is no radiation from this state. We have developed a new method for measuring excitation cross sections of metastable states. For illustration let us consider the $1s_5$ metastable state of Ne. We produce by electron impact Ne atoms in the $1s_5$ level, and use intense photon irradiation (laser) to take the atoms from the $1s_5$ level to a higher level, i.e., $2p_2$. The subsequent emission from $2p_2$ to a lower level $1s_2$ is observed and utilized to determine the electron excitation cross sections of the $1s_5$ level. We have applied this method to obtain the electron excitation cross sections of the $1s_3$ and $1s_5$ levels. This method is not limited to metastable levels. It can be used for any level with a sufficiently long lifetime. The first excited configuration $2p^53s$ of Ne consists of four levels: the two metastables ($1s_3$ and $1s_5$) and two others designated as $1s_2$ and $1s_4$ ($^1P_1$ and $^3P_1$ in LS-coupling). Because of the breakdown of the LS-coupling, the $1s_4$ level contains about a 7% admixture of singlet character. Both $1s_2$ and $1s_4$ levels radiate to the ground level. At elevated pressures radiation trapping lengthens the radiative lifetimes, so that we utilize the same technique to determine the electron excitation cross sections for the $1s_2$ and $1s_4$ states.

5. Excitation of Atoms by Heavy Particles. In the past systematic studies of excitation of different levels of a target atom by the same projectile (electron) or excitation of different target atoms by the same

projectile have been made. We have taken a new approach of studying excitation of the same target atom by different projectiles. This would allow us to delineate the effect of the projectile-target interaction on the magnitude of the excitation cross section. Specifically we measure the 3s → 3p excitation cross section of the Na atoms by collision with six different projectiles (electrons, H^+, H_2^+, H_3^+, H^o, H^-) and study its variation with respect to the projectile velocity. (Since different projectiles have different mass, we speak of the projectile velocity rather than the kinetic energy.) At incident velocities greater than 1.5×10^6 m/s the cross sections for incident electron, H^+, H_2^+, and H_3^+ are nearly the same, the cross sections for H^- excitation are similar to but somewhat smaller than the electron excitation cross sections, and the H^o excitation cross sections are much smaller. The electron excitation cross section falls to zero at its 2.1 eV threshold corresponding to a threshold velocity 8.6×10^5 m/s, but at this velocity the incident H^+, H^o, H^- all have energies much larger than 2.1 eV so their cross sections do not vanish. For incident velocities less than 1×10^6 m/s, the H^+, H_2^+, and H_3^+ cross sections are practically the same, the H^- cross sections are slightly below, but the H^o cross sections are now comparable to the H^- cross sections. From these observations we make the following conclusions: (i) At incident velocities higher than the rms velocity of the target-atom valence electrons, the dominant excitation mechanism is the direct interaction due to the charge of the projectile. (ii) At the "low incident velocity region" where the target and projectile valence electrons adjust their motion in response to the slow approach of the nuclei, the cross sections for incident H^+, H^o, and H^- should be examined in terms of NaH^+, NaH, and NaH^- molecular curves. (iii) The "large" cross sections for incident H^o at low velocities are most probably due to a two-step level-crossing transition.

Publications

"Electron-Impact Excitation of the Potassium Atom", Physical Review A 20, 1418 (1979).

"A Method for Measuring the Electron Excitation Cross Section of the Metastable $1s_5$ Level of Ne", Physical Review A 23, 2751 (1981).

"The Electron Excitation Cross Section for the Metastable $1s_3$ Level in Ne", Physics Letters 82A, 404 (1981).

"Charge-changing Cross Sections for H^- Ions Incident on a Na Vapor Target", Physical Review A 24, 44 (1981).

"Electron-Impact Excitation of the Sodium Atom", Physical Review A 24, 1299 (1981).

"Electron Excitation Cross Sections for the $1s_2$ and $1s_4$ Levels in Ne", Physical Review A 25, 1185 (1982).

"Production of Atomic Nitrogen Emission by Electron-Impact Dissociative Excitation of Nitrogen Molecules", Journal of Chemical Physics 76, 3597 (1982).

"Excitation of the Na(3p) Level by H^+, H_2^+, or H_3^+ Ions", Physics Letters 92A, 328 (1982).

"The Measurement of the Electron-Excitation Cross Sections of the Zeeman States of the Neon 1s Levels by Laser-Induced Fluorescence", Journal of Physics B, in press.

Professional Personnel

Researchers associated with this project include the following:

(a) Senior researchers: C. C. Lin (Principal investigator), L. W. Anderson, R. E. Miers, F. A. Sharpton.

(b) Graduate Students: J. S. Allen, A. B. Filippelli, J. E. Gastineau, A. M. Howald, J. O. Phelps, M. H. Phillips.

Interactions

The principal investigator has regular scientific contact with Drs. Edward T. P. Lee and Randall Murphy in the Radiation Effect Branch, Optical Physics Division of the Air Force Geophysics Laboratory (Bedford, Massachusetts).

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